ELECTROCONDUCTIVE TEXTILES

FIELD OF THE INVENTION

5   The present invention relates to electroconductive textiles and methods for producing electroconductive textiles.

BACKGROUND OF THE INVENTION

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It has been recognized for some time that the electrical properties of inherently conductive polymers (ICPs) can best be exploited by their incorporation into host structures that provide the required mechanical and
15   physical properties for a given application. Textiles produced from both naturally occurring and synthetic fibres are suited to this purpose.

Inherently conductive polymers immobilised by a
20   textile substrate could be used for a number of applications. These electroconductive textiles can be used in the production of clothing articles which function as wearable strain gauges for use in biomechanical monitoring, or direct biofeedback devices for sports
25   training and rehabilitation. In these articles physical changes in the textile cause changes to electrical resistance or electrical conductivity which can then be monitored. Other applications include the production of clothing articles which change their thermal insulation or
30   moisture transport characteristics in response to changing climatic conditions. Electroconductive textiles can also be used in applications where antistatic or EMI shielding properties are required. A further application is for use in heating devices such as car seats, car seat covers and
35   gloves.

Currently known textile materials coated with

inherently conductive polymers suffer from a number of disadvantages.

Ideally, electroconductive textiles should contain electronic components seamlessly integrated into the conventional textile structure, exhibit stable electrical properties, withstand normal wear, and be launderable. There are currently no commercially available conducting polymer coated textiles that fulfil all of these requirements. It would also be desirable for conventional textile dyeing or printing techniques to be used in the production of the electroconductive textile, however this is usually not possible due to the poor solubility properties of the inherently conductive polymers and some monomer precursors in water.

One current method used for preparing electroconductive textiles involves in situ polymerisation of the inherently conducting polymer onto a substantially non-conductive textile substrate. However, there is no apparent bonding between the non-conductive textile and the inherently conductive polymer (including some monomer precursors from which the polymer is formed). Consequently, the polymers can be easily abraded or displaced from the textile, or during laundering the textile may suffer from rapid loss of conductivity. In addition, the polymer component of the electroconductive textile can easily change oxidation state or be dedoped. Moreover, the polymer coating containing the conductive material can significantly change the properties of the non-conductive textile to which it is applied.

For similar reasons, the use of curing agents to affix conductive polymers onto the surface of textile substrates is also disadvantageous.

Another technique currently used for the production

of an electroconductive textile involves making the
textile fibres from the conductive polymer itself and
forming a fabric from the fibres. However, the nature of
conductive polymers is such that the fibres are relatively
5   brittle and inextensible and textiles formed from these
fibres also suffer from these limitations. In addition,
since the conductive polymer component of an
electroconductive textile is much more expensive than non-
conductive textiles such as cotton, wool and nylon, the
10   electroconductive textile produced by this method is
prohibitively expensive.

     Another technique explored more recently has
involved the polymerisation of conducting polymers onto
15   the chemically activated surface of a textile material.
This requires actual pre-phosphonylation of the textile
material (such as polyethylene) to create a chemically
activated textile which will bond with the conductive
polymer. Although this gives rise to a strong bond between
20   the textile and the inherently conductive polymer,
phosphonylation changes the feel or "hand" of the textile.

     The existing methods also suffer from the fact that
there are limited means besides altering the level of
25   doping to control the conductivity of the
electroconductive textile.

     Another problem associated with the current systems
for producing electroconductive textiles relates to the
30   nature of the inherently conductive polymers themselves.
A large proportion of known inherently conductive polymers
are insoluble in solvents, particularly water. This makes
it very difficult to bring the conductive polymers into
intimate contact with the textile.
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     Accordingly, it is an object of the present
invention to provide a new approach for the production of

electroconductive textiles that address these problems.

SUMMARY OF INVENTION

5   According to the present invention there is provided
an electroconductive textile comprising:
           -     a non-conductive textile,
           -     a macromolecular template which is bonded to or
                 entrapped in the non-conductive textile, and
10   -   a conductive polymer which is ordered by and
bonded to the macromolecular template;
           such that the macromolecular template binds the
conductive polymer to the non-conductive textile.

15   By using a macromolecular template of a type that is
capable of directly binding to or being directly entrapped
within the non-conductive textile (i.e. not by affixing
with an interposed curing agent), a number of advantages
are achieved. Firstly, the macromolecular template will
20   improve the conductive nature of the conductive polymer by
inducing order in the conductive polymer. In addition,
the macromolecular template and the reaction conditions
for directly coupling the macromolecular template to the
conductive polymer can be chosen to control the level of
25   conductivity of the conductive polymer.

           Another advantage of using a macromolecular template
is that a suitable preformed templated conducting polymer
can be prepared that will make the conductive polymer
30   soluble in the desired solvent, so as to facilitate the
bringing of the conductive polymer into contact with the
non-conductive textile. Similarly, a mixture of the
macromolecular template with the subunits from which the
conducting polymer is made enables solubilization of the
35   subunits in the desired solvent so as to facilitate the
bringing of the conductive polymer into contact with the
non-conductive textile. This allows for conducting

polymers to be applied to textiles using techniques that were otherwise not possible, and without the need for a curing step to bind the conducting polymer to the textile. Various other advantages associated with the use of the macromolecular template will be explained in further detail below.

According to the present invention there is also provided a method for preparing an electroconductive textile from a non-conductive textile and polymer subunits which, when polymerised, form a conductive polymer, the method comprising the steps of:

(i) polymerising the polymer subunits in the presence of a macromolecular template to form the conductive polymer bound to the macromolecular template; and

(ii) contacting the macromolecular template with the non-conductive textile to effect bonding of the macromolecular template to the non-conductive textile.

As will be explained in further detail below with reference to the main alternative techniques for preparing the electroconductive textile, step (ii) outlined above can be conducted prior to, or following step (i). Consequently, the applicant envisages three main methods by which the electroconductive textile can be prepared.

The first alternative method for preparing the electroconductive textile comprises the steps of:

(a) contacting the macromolecular template with the non-conductive textile to effect bonding of the macromolecular template to the non-conductive textile, and

(b) contacting the polymer subunits with the macromolecular template bound to the non-conductive textile, and polymerising the polymer subunits to form the conductive polymer bound to the macromolecular template and to the non-conductive textile via the macromolecular template.

The second alternative method for preparing the electroconductive textile comprises the steps of:

(a) contacting the non-conductive textile, the
5   macromolecular template and the polymer subunits with one another to effect bonding of the macromolecular template to the non-conductive textile, and bonding of the macromolecular template to the polymer subunits, and

(b) polymerising the polymer subunits to form the
10   conductive polymer which is bound to the non-conductive textile via the macromolecular template.

The third alternative method for preparing the electroconductive textile comprises the steps of:
15   (a) contacting the macromolecular template with the polymer subunits and polymerising the polymer subunits to form the conductive polymer bound to the macromolecular template, and

(b) contacting the macromolecular template with the
20   non-conductive textile to effect bonding of the macromolecular template to the non-conductive textile, with the conductive polymer bound to the non-conductive textile via the macromolecular template.

25   According to the present invention there is also provided a new use of a macromolecular template having properties which makes it capable of binding with a non-conductive textile, in the preparation of an electroconductive textile from the non-conductive textile
30   and polymer subunits which, when polymerised, form a conductive polymer.

BRIEF DESCRIPTION OF THE DRAWINGS

35   The invention is described further by way of example with reference to the accompanying drawings in which:

Figure 1 illustrates schematically the three main

techniques for forming the electroconductive textile of the present invention; and

Figure 2 is a UV/VIS Spectrum of PMAS and templated PMAS/PAn treated wool/nylon/Lycra®.

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DETAILED DESCRIPTION OF THE INVENTION

As explained above, there are three main techniques for forming the electroconductive textile of the present
10   invention.   These are schematically illustrated in Figure 1.

The first alternative method represented by (I) involves applying the macromolecular template represented
15   by A to the textile, represented by T.   In a second step the polymer sub-units represented by B are brought into contact with the macromolecular template A bound to the non-conductive textile T, and polymerisation is effected while *in situ* in the textile to produce the
20   electroconductive polymer C.   The final product, which may need to be subjected to further treatment steps such as doping, is the electroconductive textile X.

The second alternative method for preparing the
25   electroconductive textile X is represented by (II). According to this method, the macromolecular template A is contacted with the polymer subunits B, prior to or at the same time that it is contacted with the textile T.   This will yield a treated non-conducting textile T containing
30   the macromolecular template A and polymer subunits B.   In a second stage, polymerisation of the subunits B is effected to produce the electroconductive polymer C and thus yield the electroconductive textile X.

35   The third alternative method for preparing the electroconductive textile X is represented by (III).

According to this method, the macromolecular template A is brought into contact with the polymer subunits B, which are then polymerised to yield a preformed templated conductive polymer as represented by Y. The preformed templated polymer Y is then applied to the textile to yield the electroconductive textile X.

It is to be understood that the macromolecular template A and the polymer subunits B may constituted by mixtures of different materials.

In the following we have explained the meaning of the various terms used in the specification for complete understanding of the scope of the invention.

Non-conductive Textile Material

The term "textile material" or "textile" is used herein in its broadest sense and includes yarns, threads, fibres, cords, filaments, fabrics, cloths and materials that have been woven, knitted, felted, thermally bonded, hydroentangled, spunbonded, meltblown, electrospun or formed from other nonwoven processes or formed from the foregoing, and combinations thereof.

The term "non-conductive" means that the textile material is non-conductive, or has very low conductivity. Non-conductive is defined as having a surface resistivity of greater than 10^{11} $\Omega/\square$. Conductivity is the converse of resistivity, which is measured in the art in units of ohms per square ($\Omega/\square$).

The textile material may be formed from natural or synthetic fibres or a combination of the two. Natural fibres include, notably, cellulosic fibres and

proteinaceous fibres, such as cotton, hemp and wool. Synthetic fibres include the range of polymers that have been made in a fibre form, including polyalkylenes (and homopolymers or copolymers; examples of the homopolymers being polyacrylonitrile and polypropylene); polyamides including nylon (such as nylon 6 and nylon 66), Kevlar® and Nomex®; polyurethanes, including polyurethane block copolymers (such as Lycra®); polyureas (and block copolymers thereof such as polyurethaneureas); polyesters such as polyethylene terepthalate (PET); and synthetic cellulose-derived fibres, such as rayon, and combinations thereof.

According to one embodiment, the non-conductive textile is a natural fibre-containing textile, suitably a wool-containing textile.

Due to the choice of templates and conductive polymers used, the non-conductive textiles do not need to be subjected to a functionalisation reaction (sometimes required in the art) for fixation purposes. Thus, according to one embodiment, the non-conductive textiles used in the present invention are not subjected to a functionalisation reaction to make it possible for a covalent bond to be formed between the textile and the macromolecular template on later application of the macromolecular template. Preferably, the non-conductive textile also contains no phosphonylation.

Similarly, the textiles can be made electroconductive by techniques that do not require a curing step to bind the conducting polymer to the textile. This is also an advantage of the present invention.

Conductive Polymer

The term "conductive polymer" is used broadly to refer to any of the class of conductive polymers known in the art. These are sometimes referred to as "inherently conductive polymers" or "intrinsically conductive polymers".

Conductive polymers are unsaturated polymers containing delocalised electrons and an electrical charge. Conductive polymers may be positively or negatively charged (cationic or anionic), and are associated with counter ions referred to as the dopant. Polymers in the main class of conductive polymers are polymerised from their polymer subunits by oxidation. These will be referred to as the oxidatively polymerised conductive polymers.

The term "conductive polymer" is used in its broadest sense to refer to doped and dedoped conductive polymers, and therefore it encompasses any of the polymers which form polaronic (including bipolaronic) moieties. Generally, polarons are the charge carrying species which are generated by the oxidation of the conjugated polymer backbone.

Examples of suitable conductive polymers are polypyrrole and its derivatives, polythiophene and its derivatives, phenyl mercaptan and its derivatives, polycarbazole and its derivatives, polyindole and its derivatives and polyaniline and its derivatives, or combinations thereof. Suitable derivatives are those that contain functional groups, such as a methoxy group. Examples within the range of other optional functional

groups are alkyl, alkenyl, alkynyl, aryl, halo, haloalkyl, haloalkenyl, haloalkynyl, haloaryl, hydroxy, alkoxy, alkenyloxy, aryloxy, benzyloxy, haloalkoxy, haloalkenyloxy, haloaryloxy, nitro, nitroalkyl,

5   nitroalkenyl, nitroalkynyl, nitroaryl, nitroheterocyclyl, amino, alkylamino, dialkylamino, alkenylamino, alkynylamino, arylamino, diarylamino, benzylamino, dibenzylamino, acyl, alkenylacyl, alkynylacyl, arylacyl, acylamino, diacylamino, acyloxy, alkylsulfonyloxy,

10   arylsulfenyloxy, heterocyclyl, heterocycloxy, heterocyclamino, haloheterocyclyl, alkylsulfenyl, arylsulfenyl, carboalkoxy, carboaryloxy, mercapto, alkylthio, benzylthio, acylthio, sulfonate, carboxylate, phosphonate and nitrate groups or combinations thereof.

15   The hydrocarbon groups referred to in the above list are preferably 10 carbon atoms or less in length, and can be straight chained, branched or cyclic.

Dopant

20   Dopants or doping agents provide the counter ions which are associated with the conductive polymers. These may be derived from strong acids such as p-toluene sulfonic acid, naphthalene disulfonic acid, methane sulfonic acid, chloromethyl sulfonic acid, fluoromethyl

25   sulfonic acid, oxalic acid, sulfosalicylic acid and trifluoroacetic acid. However, as explained below, the dopant may be provided by the macromolecular template or another agent (for example, the acid moiety of the functional groups present in any reagent used in forming

30   the electroconductive textile). Oxidizing agents such as ammonium persulfate, ammonium peroxydisulfate, iron (III) chloride, salts of permanganates, peracetates, chromates and dichromates may contribute to the doping effect.

Polymer Sub-units

The term "polymer sub-unit" is used herein to refer to monomers, dimers, multimers (eg oligomers) and mixtures
5   thereof that, upon polymerisation, form a polymer. In the context, the polymer formed may be a conductive polymer. The polymer subunits which form the conductive polymer may be the same or different. Furthermore, the dimer and multimer may be formed from monomer units which are the
10   same or different. Consequently, the conductive polymer may be a homopolymer or a copolymer.

Examples of suitable polymer sub-units are aniline, thiophene, bithiophene, terthiophene, pyrrole, phenyl
15   mercaptan, indole, carbazole, and derivatives thereof. Pyrrole, thiophene and aniline and their derivatives are particularly preferred.

Polymer
20   The term "polymer" is used in its broadest sense to encompass homopolymers, copolymers, oligomers and so forth, unless the context is to the contrary.

Macromolecular template
25   The term "molecular template" refers to any chemical, compound, substance or mixture thereof that provides a template upon which, or in relation to which, the polymer subunits of the conductive polymer will preferentially align to induce the desired orientation of
30   the subunits for forming the conductive polymer. For instance, where the polymer is to be preferentially para-directed during synthesis, an appropriate template is one which causes the polymer subunits to be aligned to form a

complex with the template that leads to mostly para-directed synthesis, with limited alternative branching. The prefix "macro" means that the molecular template is a macromolecule in size. A macromolecule is defined as a

5 molecule of high relative molecular mass, the structure of which essentially comprises the multiple repetition of units derived, actually or conceptually, from the molecules of low relative molecular mass. To avoid any doubt, we note that porphyrins, large dyestuffs and

10 similar compounds are encompassed by the expression "macromolecule". Generally, macromolecules have a molecular weight of about 1000 or more, suitably 1200 or more. The term "macromolecular template" encompasses polymeric molecular templates, and indeed particular

15 embodiments of the invention utilise polymeric molecular templates.

Although a large range of substances are known to function as "molecular templates" in a broad sense, it is

20 noted that the macromolecular templates of the present invention must be compounds that are capable of bonding with or being entrapped within the non-conductive textile. Consequently, not all materials described in the prior art as molecular templates function as macromolecular

25 templates as defined in the present application.

The templates of the present invention are "molecular" in that they provide template-guiding on a molecular level, rather than a physical level.

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The macromolecular templates provide strands or a structured surface area upon which the polymer subunits that form the conductive polymer can be bound in an

ordered fashion by non-covalent intermolecular interactions to form a stable molecular complex.

The macromolecular templates may be non-conductive or conductive. The use of conductive macromolecular templates is of particular interest, as they can add to the conductive properties of the electroconductive textile themselves.

Electrically conductive macromolecular templates, and particularly polymeric molecular templates, encompass conductive polymers containing one or more acid, ester or salt (electrolyte) groups, and derivatives thereof. The acid or ester group is one that contains a carbon, sulfur, nitrogen or phosphorous to oxygen double bond, and a single bond from said carbon, sulfur, nitrogen or phosphorous atom to another oxygen (or sulfur or nitrogen) atom. Accordingly, this class of functional groups includes sulfates, sulfonates, carboxylates, phosphonates, nitrates, amides, and the acid equivalents (such as sulfonic acid, carboxylic acid, and so forth) and derivatives thereof. Sulfonate and sulfate groups are preferred. Such conductive macromolecular templates containing sulfonate and/or sulfate may be fully or partially sulfonated.

These conductive polymers may contain any other functional groups, such as a methoxy group. Examples within the range of other optional functional groups are alkyl, alkenyl, alkynyl, aryl, halo, haloalkyl, haloalkenyl, haloalkynyl, haloaryl, hydroxy, alkoxy, alkenyloxy, aryloxy, benzyloxy, haloalkoxy, haloalkenyloxy, haloaryloxy, nitro, nitroalkyl,

nitroalkenyl, nitroalkynyl, nitroaryl, nitroheterocyclyl, amino, alkylamino, dialkylamino, alkenylamino, alkynylamino, arylamino, diarylamino, benzylamino, dibenzylamino, acyl, alkenylacyl, alkynylacyl, arylacyl,

5   acylamino, diacylamino, acyloxy, alkylsulfonyloxy, arylsulfenyloxy, heterocyclyl, heterocycloxy, heterocyclamino, haloheterocyclyl, alkylsulfenyl, arylsulfenyl, carboalkoxy, carboaryloxy, mercapto, alkylthio, benzylthio and acylthio. The hydrocarbon

10   groups referred to in the above list are preferably 10 carbon atoms or less in length, and can be straight chained, branched or cyclic.

    A preferred class of conductive macromolecular

15   templates encompasses the sulfonated polyanilines, sulfonated polypyrroles, and sulfonated polythiophenes, and derivatives thereof. The expression "derivatives thereof" means that the compounds contain one or more of the functional groups outlined above. One particularly

20   useful molecular template within this class is poly 2-methoxyaniline-5-sulfonic acid (PMAS).

    Examples of non-conductive macromolecular templates which can be used are polyvinylsulfonate, polystyrene

25   sulfonates, biologically active polymers such as heparin, chondroitin sulfate and dextran sulfate, as well as large multicharged ions such as calixarenes, cyclodextrins and selected polymeric textile dyestuffs. Although these compounds are non-conductive, they can provide dual

30   functions. For instance, these compounds function as macromolecular templates, and may also function as a dopant or dye for colouring of the textile.

Thermally sensitive polyelectrolytes such as poly-2-acrylamido-2-methyl propane sulfonic acid (PAMPS) and co-polymers comprising the AMPS monomer are other examples of macromolecular templates which can be used.

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Redox containing polyelectrolytes such as polyvinyl ferrocene sulfonate are other examples of macromolecular templates that provide a function in addition to the molecular template function. Other classes of

10 macromolecular templates that provide a dual function comprise UV absorbers, fluorescent whitening agents, stain blocking agents and shrinkproofing polymers which are also macromolecular templates. It is to be noted, however, that not all UV absorbers, fluorescent whitening agents,

15 stain blocking agents and shrinkproofing polymers are or can act as macromolecular templates.

As mentioned above, the macromolecular template may be conductive, and in this instance the macromolecular

20 template can be either a cationic or anionic conductor. Cationic macromolecular templates may be used to bind an anionic conductive polymer to the non-conductive textile. Similarly, an anionic macromolecular template may be used to bind a cationic conductive polymer to the non-

25 conductive textile.

Polyelectrolytic molecular templates are the preferred class of macromolecular templates, and an example includes PMAS.

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In a preferred embodiment, the macromolecular template can provide an environment for facile oxidation of the polymer subunits to form the conductive polymer.

Bound

The term "bound" or "bonded" or "bind" refers to non-covalent or covalent intermolecular interactions between two compounds. Hydrogen bonding is encompassed by this term. This term is used in the sense of direct bonding between two compounds without an interposed agent such as a curable adhesive. Covalent bonding refers to the direct interaction between the macromolecular template and the textile, or the macromolecular template and the conducting polymer. Non-covalent bonding encompasses ionic intermolecular interactions sufficient to bond one surface directly to the other without any interposed agent such as an adhesive.

One test for determining whether the conductive polymer is bound to the non-conductive textile via the macromolecular template only as required herein involves subjecting the product to sonication to detect evidence of loss of the conductive polymer from the textile. Removal of conductive polymer during the sonication test indicates that the conductive polymer is not bound by the intermolecular interactions. Another simple test correlates to the standard test used in fabric dyeing to determine whether a colouring agent has bonded to the fabric or not. This involves rubbing the textile against white fabric. Marking of the white fabric demonstrates that the dye has not bonded to the fabric.

In the non-printing methods for applying the conductive polymer to the non-conductive textile, the mechanism of binding is preferably not a curing mechanism.

Entrapment

The expression "entrapped in" refers to the situation where the macromolecular template forms an interpenetrating network through the textile fibre matrix.

5 The expression "interpenetrating network" is well understood in the field of polymers and is used in the same sense here. It involves the polymer chains extending into the textile fibre matrix and being entrapped therein without direct covalent chemical bonding.

10

Polymerisation

The polymer sub-units are polymerised by any process appropriate for the particular monomers involved. This encompasses addition polymerisation or condensation

15 polymerisation, with free radical initiation, where required, produced by redox reaction, light or microwave. Usually the polymerisation is by way of addition polymerisation for the production of the conductive polymer.

20

The contacting of the various components with one another in the methods of the invention can be achieved by any appropriate technique. Advantageously this is achieved by one of the conventional textile dyeing

25 techniques, including padding, exhaustion, printing and coating including foam applications.

Products made from electroconductive textiles

The electroconductive textiles of the present

30 invention may be used to manufacture articles requiring electroconductive properties. The articles may be made partly or entirely from the electroconductive textile. Examples include gloves, car seats, heating panels for car

seats, protective clothing, hosiery, and other apparel items, footwear, headgear, strain gauges, energy storage devices such as batteries or capacitors, and energy conversion devices.

The present invention provides additional functionality, and overcomes compatibility issues of some conductive polymers with non-conductive textiles when the prior art is employed. The present invention also provides a means of locating the conductive polymer either inside the non-conductive textile or on its surface, thereby allowing users to further tailor electroconductive textiles to suit individual applications and requirements.

Other Product and Process Options

As indicated above, the macromolecular template can itself be a conductive polymer. In this situation, the electroconductive textile comprises a non-conductive textile, having a conductive macromolecular template bonded thereto, and a conductive polymer (which may be the same substance or a different substance to the macromolecular template) bonded thereto. It is also possible, according to this embodiment or any other embodiment, to apply to the 3 component electroconductive textile one or more further layers of conductive polymer.

EXAMPLES

A number of preferred embodiments are described by reference to the following non-limiting examples.

Most of the examples provided below utilise poly 2-methoxyaniline-5-sulfonic acid (PMAS) as the

macromolecular template. This macromolecular template is itself a conductive polymer, and therefore some electrical resistivities are reported for textiles to which the macromolecular template has been applied. However, to

5   avoid misunderstanding, it is noted that not all conductive polymers are capable of functioning as a macromolecular template which both provide the templating function for the conductive polymer, and bond to a non-conductive textile. Nevertheless, as these precursors in

10 the preparation of the electroconductive textiles of the present invention do have conductive properties, their levels of electrical resistivity have been reported on occasion in the following examples.

15 Furthermore, in the examples, the % exhaustion (for example, of molecular template onto non-conductive textile) was determined from UV/VIS absorption spectroscopy. For PMAS, this was calculated from the 474nm absorption peak. The measurements were taken at the

20 end of the process step (eg after 4 hours and 30 minutes application time). This is confirmed in the Tables where * is marked.

The values for electrical surface resistivity

25 reported were determined using a modification of the AATCC Test Method 76 - 1995 Electrical Resistivity of Fabrics, and represent the mean and standard deviation of 3 readings on a single textile treatment. The electrical resistance of the treated fabrics was measured on a

30 measurement rig consisting of 2 copper bars spaced 1.5cm apart embedded in a Perspex base and 2 copper bars which sat atop the fabric. The textile sample had been conditioned at 20°C and 65%RH for a period of 2 hours

before measurement. After placement of the textile between the copper bars, a 1kg weight was placed atop the rig, and an electrical resistance measurement was taken after 60 seconds. Electrical resistance values were converted to electrical surface resistivity, and quoted as $\Omega/\square$.

1. FIRST ALTERNATIVE METHOD FOR FORMING ELECTROCONDUCTIVE TEXTILE

1.1 Step 1: Application of Macromolecular Templates to Non-Conductive Textiles

In this Section we demonstrate methods for applying the macromolecular template of the preferred embodiment of the invention to a non-conductive textile. Whilst this corresponds directly to the first step of the first alternative method for forming the electroconductive textile of the invention, the same techniques apply to any of the steps of the second and third alternative methods (illustrated in Figure 1) in which a macromolecular template is contacted with the non-conductive textile, irrespective of whether or not the macromolecular template has already been contacted with the polymer subunits.

1.1.1 Exhaust Application of PMAS onto Wool-based Textiles

PMAS [10% on mass of fabric (omf)] was applied to a scoured chlorine-Hercosett treated wool knit textile using an Ahiba Texomat Laboratory Dyeing Machine with the wool textile being wound onto a spindle and submerged in the application liquor. A liquor:goods ratio of 50:1 was used and the PMAS application was made to 2g sample of textile which had been wet out prior to use by soaking at room temperature for 10 minutes in 1g/L Lissapol TN450 (ICI,

non-ionic surfactant) followed by a distilled water rinse and a final 10 min soak in acid solution at the desired pH.

5   The PMAS solution was adjusted to pH 1.4 by the drop-wise addition of 10% w/v H_2SO_4 to the stirred solution. The wool textile was introduced to the application bath at 40°C, heated to 90°C over 30 minutes, and the temperature maintained for a further 4 hours. The

10   textile sample was then removed from the application liquor and rinsed in cold tap water until no signs of "bleed" were evident. Excess water was removed and the sample was air-dried at room temperature overnight prior to measurement of the electrical resistivity.

15

This basic process was used for the application of the macromolecular template to the non-conductive textile unless otherwise stated.

20   1.1.2 Variation of Application pH

The process outlined in 1.1.1 above was repeated with modification of the initial pH of the PMAS application liquor. The results of these trials are

25   demonstrated in Table 1.

Table 1:

Initial pH	Final pH	Final % PMAS Exhaustion*	Textile Electrical Resistivity
2.7	4.2	50.0	454 +/- 59 GΩ/□
2.0	2.5	52.7	8.3 +/- 0.3 GΩ/□
1.8	2.0	60.3	1.3 +/- 0.1 GΩ/□
1.6	1.8	71.5	334 +/- 29 MΩ/□
1.4	1.5	86.3	160 +/- 11 MΩ/□

These trials demonstrate that PMAS uptake is dependent upon the application pH. Lowering the initial pH results in increased uptake of the PMAS and decreased electrical resistivity of the treated textile.

Non-conductive textiles other than wool can be subjected to an application pH of less than pH 1.4 due to better stability of the textile in acid at the process temperatures. Wool non-conductive textiles, however, are preferable treated at pH 1.4 or above. Under these conditions the wool textiles produced were structurally intact, with no obvious weakening of the textile integrity. The coated textiles could be stretched up to 70%, without tearing.

1.1.3 Variation in Application Temperature

The process outlined in 1.1.1 above was repeated with modification of the temperature of the PMAS application liquor. The results of these trials are set out in Table 2.

Table 2:

Appl. Temp. (°C)	Initial pH	Final pH	Final % PMAS Exhaustion*	Textile Electrical Resistivity
60	1.4	1.4	38.0	14.4 +/- 0.5 GΩ/□
70	1.4	1.4	38.7	2.4 +/- 0.1 GΩ/□
80	1.4	1.4	51.9	410 +/- 21 MΩ/□
90	1.4	1.5	86.3	160 +/- 11 MΩ/□
100	1.4	1.5	100.0	828 +/- 32 MΩ/□

Higher application temperatures are preferred for maximising uptake of the macromolecular template, although ultimately the temperature used may be influenced by other

factors such as electrical resistivity and textile deterioration.

1.1.4 Variation in Acid Used to Adjust pH

The standard method outlined in 1.1.1 for the uptake of PMAS on wool was repeated with the substitution of the sulfuric acid with other acids. The result of this trial is set out in Table 3.

Table 3:

Acid	Initial pH	Final pH	Final % PMAS Exhaustion*	Textile Electrical Resistivity
H_2SO_4	1.4	1.4	96.8	227 +/- 13 MΩ/□
HCl	1.4	1.5	99.9	4.0 +/- 3.2 GΩ/□
p-Toluene Sulfonic Acid	1.4	1.5	92.3	280 +/- 1 MΩ/□
10-Camphor Sulfonic Acid	1.4	1.5	87.3	176 +/- 1 MΩ/□

1.1.5 Variation in PMAS Concentration

The process outlined in 1.1.1 above was repeated with modification to the PMAS concentration, measured as a percentage based on the mass of the non-conductive textile. The results of these trials are set out in Table 4.

Table 4:

Initial PMAS Conc. (% omf)$^\textit{ε}$	Final pH	Final % PMAS Exhaustion*	Textile Electrical Resistivity (MΩ/□)
5	1.5	99.4	804 +/- 21
10	1.5	71.1	88.6 +/- 1.9
15	1.4	59.3	71.3 +/- 1.1
20	1.4	46.9	80.9 +/- 1.1

$^\textit{ε}$ "omf" refers to "on mass of fabric".

1.1.6 Variation of Macromolecular Template

1.1.6.1   Other Conductive Macromolecular Templates

Other water-soluble conductive templates can be used in place of PMAS. Partially sulfonated polyaniline, with sulfonation on ~ 80% on the aniline rings was produced from polyaniline by the method using chlorosulfonic acid. Application of the partially sulfonated polyaniline to scoured chlorine-Hercosett treated wool knit textile was performed using the same conditions described in 1.1.1 for PMAS. This application resulted in an exhaustion of 80.0% of the partially sulfonated polyaniline onto the textile material, affording it an electrical resistivity of 790 +/-13 MΩ/$\square$.

Similarly, PMAS was substituted by water-soluble copolymers of the 2-methoxyaniline-5-sulfonic acid monomer (MAS), and aniline (AN). Copolymers with MAS/AN molar feed mix ratios varying from 19:1 to 4:1 have been prepared and evaluated. They have been found to provide a similar conductive effect to PMAS, with electrical resistivities as low as 35 +/-3 MΩ/$\square$ being recorded for wool knit textile samples prepared from the copolymers by the same conditions for PMAS.

1.1.6.2   Non-conductive Macromolecular Templates

The method outlined in 1.1.1 above was repeated with the replacement of the PMAS with a range of other macromolecular templates applied at 10% offer based on mass of fabric. The results of the exhaustion levels from

this study, as determined by UV/VIS, are set out in Table 5 below:

Table 5:

Macromolecular Template	% Exhaustion level
Basyntan D liquid (BASF)	80
Seicitan D Liquid (Seici)	76
Intan EMS (Alpa)	96
Trupotan R83 (Trumpler)	42
Synthaprett BAP (Bayer)	34
Orotan SN Powder (Bayer)	90
Poly (styrene sulfonic acid/maleic acid) (Polysciences Inc.) 3:1 or 1:1	75-80
Dextran Sulfate	97*

5   * Exhaustion of dextran sulfate was determined by toluidine blue assay. Similar levels of exhaustion of dextran sulfate were obtained for 20, 30, 40 and 50% offers based on mass of wool fabric

1.1.7 Variation of Non-Conductive Textile.

10

    The process outlined under 1.1.1 above was repeated with the substitution of the wool textile described there with the following textile composites:

15   wool/nylon/Lycra®;
    wool/polyester;
    nylon;
    nylon/Lycra®; and
    cotton.

20

    3 different wool/nylon/Lycra® fabrics were used. They ranged in wool content from 90-97%, nylon 2-8%, and

Lycra® 0.5-1%, and were of approximately 270g/m^2 density. These fabrics were manufactured by the applicant, and have commercially available equivalents.

5   The nylon and nylon/Lycra® were commercially available textiles obtained from a retailer of fabrics. The cotton was a scoured fabric that again was knitted by the applicant, having similar properties to commercially available cotton fabric.

10

The wool-based templated textiles produced had similar electrical resistivity to the 100% wool textiles reported in 1.1.1 above.

15   1.1.8 Other Application Techniques for PMAS

Examples 1.1.1 – 1.1.7 all relate to the application of the macromolecular template to the non-conductive textile by the exhaust technique, in which the non-
20   conductive textile is saturated in an application liquid containing the macromolecular template. In the following we have exemplified other application techniques.

1.1.8.1   Padding

25

An aqueous pad liquor (100ml) was prepared containing 33.3g/L PMAS at 20°C. The unadjusted pH of the pad liquor prior to use was 1.2. A 2g sample of wool textile was wet out prior to being padded by soaking in an
30   aqueous solution of 1g/L Lissapol TN450 (non-ionic surfactant, ICI) at 20°C for 10 minutes. The fabric was rinsed at room temperature with distilled water and then passed through squeeze rollers set to provide 100% pickup.

The damp fabric was then added to the pad liquor, the fabric allowed to become saturated with the liquor over 2 minutes with mild agitation by hand, then withdrawn and passed through squeeze rollers that provided a pickup of

5   225%. These conditions had the effect of applying 7.5% omf PMAS to the textile sample. After this treatment, the sample was placed in an airtight plastic bag and "batched" at 20°C in the dark for 24 hours. Following this period, the sample was removed from the plastic bag and rinsed in

10   cold tap water until free of "bleed", dried overnight at room temperature and the electrical resistivity of the textiles was then measured to be 870 +/- 11 MΩ/□.

1.2   Step 2: Contacting of Templated Textile with Polymer
15   Subunits and *In situ* Polymerisation

1.2.1 *In Situ* Polymerisation of Aniline on PMAS Pre-
        treated Wool Textiles

20   A sample of the PMAS treated textile of Example 1.1.1 was wound onto a spindle and wet out by soaking at room temperature for 10 min in 1 g/L Lissapol TN450 (ICI, non-ionic surfactant) followed by a distilled water rinse. Aniline was added to distilled water (80 ml) and after

25   stirring for 30 min, the pH was adjusted to pH 1.4 by the drop-wise addition of a 10% w/v solution of sulfuric acid and the final volume was made up to 85 ml.

The spindle was placed in the aniline solution and
30   stirred for 15 min using an overhead stirrer (60 rpm). The *in situ* polymerisation was brought about by the drop-wise addition of a solution of ammonium persulfate in distilled water (15 ml) over a 15 min period to the

mixture, which was then left to stir for a further 16 h at room temperature. After the 16 h, the sample was removed, rinsed in cold water and allowed to air dry at room temperature. A significant decrease in electrical
5 resistivity from 160 MΩ/$\square$ for the PMAS treated wool to 69 KΩ/$\square$ for the templated textile after the *in situ* polymerisation process was observed.

1.2.2 Variation in PMAS:Aniline Ratio

10

The method outlined in 1.2.1 above was repeated with modifications to the molar PMAS:aniline ratio. The results are set out in Table 6. The results show that there is an optimum molar ratio of PMAS:aniline of approximately 1:2,
15 at a constant aniline:oxidant ratio of 1:0.25.

Table 6:

PMAS:Aniline Ratio	PMAS:Aniline:Oxidant Ratio^	Templated Textile Electrical Resistivity(MΩ/$\square$)
1:1	1:1:0.25	8.0
1:2	1:2:0.5	1.9
1:3	1:3:0.75	3.4

^   Polymerisation using constant 1:0.25 aniline: ammonium persulfate ratio in each case.

20

1.2.3 Variation of Aniline:Oxidant Ratio

The method outlined in 1.2.1 above was repeated with modifications to the aniline:oxidant molar ratio, where
25 the PMAS:aniline ratio was held constant at 1:2. The results are set out in Table 7. It was found that the range of ratios between 1:0.25 - 1:0.5 afforded the lowest electrical resistivity for wool-based textiles.

Table 7:

Aniline:Oxidant Ratio	PMAS:Aniline:Oxidant Ratio	Templated Textile Electrical Resistivity
1:0.125	1:2:0.25	3.7 +/- 0.3 MΩ/□
1:0.25	1:2:0.5	136.2 +/- 0.8 KΩ/□
1:0.5	1:2:1	154.6 +/- 16 KΩ/□
1:1	1:2:2	2.9 +/- 0.5 MΩ/□

1.2.4 Variation in PMAS Concentration

5   The method outlined in 1.2.1 above was repeated, with the modification that the PMAS treated textiles used were not those of Example 1.1.1, but those of 1.1.5, having a concentration of PMAS (measured as a percentage based on the mass of the non-conductive textile - that is

10   %omf) of 5%, 10%, 15% and 20%. The results are set out in Table 8. Increasing the PMAS concentration from 5-15% omf results in a decrease in the electrical resistivity of templated textiles. However, further increases in PMAS concentration were shown to have only marginal influence.

15

Table 8:

Initial PMAS Conc. (% omf)	Final % PMAS Exhaustion*	PMAS conc. in Textile (% omf)	Templated Textile Electrical Resistivity (KΩ/□)
5%	99.4	5%	874 +/- 21
10%	71.1	7.1%	126.3 +/- 2.1
15%	59.3	8.9%	87 +/- 1.1
20%	46.9	9.4%	83 +/- 1.1

1.2.5 Variation of Polymerisation Temperature

20   The method outlined in 1.2.1 above was repeated with modifications to the polymerisation temperature. The results are set out in Table 9. The molecular templated textiles were found to have a lower electrical resistivity when the polymerisation was carried out at ambient

25   temperature.

Table 9:

Polymerisation Temperature (°C)	Templated Textile Electrical Resistivity
38	1.1 +/- 0.1 MΩ/□
23	126.3 +/- 2.1 KΩ/□
2.3	275.0 +/- 18.7 KΩ/□

1.2.6 Variation of polymerisation pH

The method outlined in 1.2.1 above was repeated with modifications to the polymerisation pH. The results are set out in Table 10.

Table 10:

Initial pH	Final pH	PMAS Treated Textile Resistivity (MΩ/□)	Templated Textile Electrical Resistivity
4.0	2.7	79.3	2.2 +/- 0.1 MΩ/□
2.4	2.4	90.2	422 +/- 16 KΩ/□
1.4	1.6	76.6	262 +/- 21 KΩ/□

1.2.7 Variation of Acid Used to Adjust pH of
      Polymerisation Solution

The method of Example 1.2.1 was repeated with the replacement of the sulfuric acid with hydrochloric acid. The results are set out in Table 11.

Table 11:

Acid	Templated Textile Electrical Resistivity (KΩ/□)
H_2SO_4	126.3 +/- 2.1
HCl	558 +/- 5

2   SECOND ALTERNATIVE METHOD FOR FORMING
     ELECTROCONDUCTIVE TEXTILE

2.1   Contacting of PMAS and Aniline to Wool Textile, and
5   *in situ* Polymerisation of PMAS/Aniline Pretreated
       Textiles.

       A PMAS/aniline mixture was simultaneously applied to
       scoured chlorine-Hercosett treated wool knit textile using
10   an Ahiba Texomat Laboratory Dyeing Machine. The wool
       textile was wound onto a spindle and submerged in the
       application liquor. The spindle was given constant, steady
       agitation by the dyeing machine during the course of the
       application. A standard liquor:goods ratio of 50:1 was
15   used throughout, and the application was made to a 2g
       sample of wool which had been wet out prior to use by
       soaking at room temperature for 10 minutes in 1g/L
       Lissapol TN450 (ICI, non-ionic surfactant) followed by a
       distilled water rinse and a final 10 min soak in acid
20   solution at the desired pH.

       The PMAS/aniline mixture solution was adjusted to pH
       1.4 by the drop-wise addition of acid (10% w/v H_2SO_4) to
       the stirred solution. The wool textile was introduced to
25   the application bath at 40°C, heated to 90°C over 30
       minutes, and maintained at this temperature for a further
       4 hours. After the completion of the application, the
       mixture was allowed to cool to room temperature. The *in
       situ* polymerisation was brought about by the drop-wise
30   addition of a solution of ammonium persulfate in distilled
       water (15 ml) over a 15 min period to the mixture, which
       was then left to stir for a further 16 h at room
       temperature. After the completion of the application, the

textile sample was removed from the application liquor and rinsed in cold tap water until no signs of "bleed" were evident. Excess water was removed and the sample was air-dried at room temperature. The wool textiles prepared

5 using this method had electrical resistivities in the range from 80 KΩ/□ to 668 KΩ/□.

3 THIRD ALTERNATIVE METHOD FOR FORMING ELECTROCONDUCTIVE TEXTILE

10

3.1 Step 1: Synthesis of Preformed Templated Polymers

A series of templated polymers were prepared in the presence of 0.02M PMAS using different concentrations of

15 aniline, as set out in Table 5. Aniline was added to an aqueous solution of PMAS and the resulting solution's pH of about 5.4 was adjusted to pH 2.0 by the addition of HCl (conc.). The required amount of ammonium persulfate solution to facilitate the polymerisation (set out in

20 Table 12) was added drop-wise at such a rate as to maintain the reaction temperature below 24°C. The thick polymer solution obtained was stirred overnight and then dialysed by using 12kD dialysis tubing. After dialysis the polymer solution was stirred and heated to about 50°C

25 to concentrate the polymer, and then left to dry by evaporation in a fume hood. The conductivities of pressed pellets of the templated polymers were then measured, and the results are set out in Table 12. Conductivities of pressed pellets as high as 6.8 S/cm were obtained.

30

Table 12:

Molecular Templating Concentrations	Oxidant Concentration $(NH_4)_2S_2O_8$	Solid Pellet Conductivity (S/cm)	pH
PMAS + Aniline (0.02M + 0.02M)	0.02M	0.05	2.0
PMAS + Aniline (0.02M + 0.06M)	0.06M	6.8	2.0
PMAS + Aniline (0.02M + 0.08M)	0.08M	5.1	1.9
PMAS + Aniline (0.02M + 0.05M)	0.055M	1.2	2.0
PMAS + Aniline (0.02M + 0.037M)	0.02M	1.0	2.1

3.2   Step 2: Application of Preformed Molecular Template to Non-conductive Textile

5

The PMAS/PAn (polyaniline) preformed template and conductive polymer of Example 3.1 containing PMAS:Aniline:oxidant ratio 0.02M:0.06M:0.06M was applied to scoured chlorine-Hercosett treated wool knit textile

10   using an Ahiba Texomat Laboratory Dyeing Machine. The wool textile was wound onto a spindle and submerged in the application liquor, and the spindle was given constant, steady agitation by the dyeing machine during the course of the application.   A standard liquor:goods ratio of

15   50:1 was used throughout this example, and the application was made to a 2g sample of textile which had been wet out prior to use by soaking at room temperature for 10 minutes in 1g/L Lissapol TN450 (ICI, non-ionic surfactant) followed by a distilled water rinse and a final 10 min

20   soak in acid solution at the desired pH.

The PMAS/PAn template solution was adjusted to pH 1.4 by the drop-wise addition of acid (10% w/v H_2SO_4) to the stirred solution. The wool textile was introduced to

25   the application bath at 40°C, heated to 90°C over 30

minutes, and this temperature maintained for a further 4 hours. After the completion of the application, the textile sample was removed from the application liquor and rinsed in cold tap water until no signs of "bleed" were evident. Excess water was removed and the sample was air-dried at room temperature. The products were found to have electrical resistivity values in the range of 2.7-26.7 MΩ/$\square$.

3.2 Application of Other Preformed Templates

The preformed template, poly(styrenesulfonate)/poly(2,3-dihydrothieno[3,4-b]-1,4-dioxin (PSS/PEDOT) was applied to the scoured chlorine-Hercosett treated wool knit textile. The wool textile was wound onto a spindle and submerged in the application liquor, and the spindle was given constant, steady agitation during the course of the application. A liquor:goods ratio of 60:1 was used and the application was made to a 1g sample of textile which had been wet prior to use by soaking at room temperature for 10 minutes in 1g/L Lissapol TN450 (ICI, non-ionic surfactant) followed by a distilled water rinse and a final 10 min soak in acid solution at the desired pH.

The PSS/PEDOT template solution was adjusted to pH 1.4 by the drop-wise addition of acid (10% w/v HCl) to the stirred solution. The wool textile was introduced to the application bath at 40°C, heated to 90°C over 30 minutes, and this temperature maintained for a further 4 hours. After the completion of the application, the textile sample was removed from the application liquor and rinsed in cold tap water until no signs of 'bleed" were evident.

Excess water was removed and the sample was air-dried at room temperature. The product was found to have an electrical resistivity value of 74.8 +/- 3.2 KΩ/□.

5 4   USE OF OTHER MACROMOLECULAR TEMPLATES AND CONDUCTIVE POLYMERS.

Experiments using Method I (see Figure 1) where polystyrene sulfonate (PSS⁻) (MWt 70,000) is the
10   macromolecular template showed that this polyelectrolyte can also assist in the incorporation of polyaniline into wool/nylon/Lycra®. Further experiments also with Method I showed that by using PMAS as a template, other conducting polymers could also be incorporated into
15   wool/nylon/Lycra®.

4.1   *In situ* Polymerization of Other Conducting Polymers onto PMAS Treated Wool Fabrics

20   4.1.1 Templating of Polypyrrole onto PMAS-treated Wool Fabric

The PMAS/polypyrrole templated fabric was formed by *in situ* polymerisation of pyrrole using method I to PMAS-
25   treated chlorine-Hercosett wool prepared by the procedure of 1.1.1. (Table 13)

A sample of the PMAS treated textile of Example 1.1.1 was wound onto a spindle and wet out by soaking at
30   room temperature for 10 min in distilled water. Pyrrole was added to distilled water (80 ml) and after stirring for 30 min, the pH was adjusted to pH 1.4 by the drop-wise

addition of a 10% w/v solution of sulfuric acid, and the final volume was made up to 85 ml.

The spindle was placed in the pyrrole solution and
5   stirred for 15 min using an overhead stirrer (60 rpm).
The *in situ* polymerisation was brought about by the drop-
wise addition of a solution of iron(III) chloride
hexahydrate in distilled water (15 ml) over a 5 min period
to the mixture, which was then left to stir for a further
10 3 h at room temperature. After 3 h, the sample was
removed, rinsed in cold water and allowed to air dry at
room temperature. A significant decrease in electrical
resistivity from 160 MΩ/$\square$ for the PMAS treated wool to 69
KΩ/$\square$ for the templated textile after the *in situ*
15 polymerisation process was observed.

The use of other reagents such as hydrochloric acid,
anthraquinone-2-sulfonic acid, 1,5-naphthalene disulfonic
acid can be used as a replacement for, or in addition to
20 the sulfuric acid to prepare the PMAS/polypyrrole
templated fabrics. Alternatively the polypyrrole can be
formed using ammonium persulfate as oxidant.

Table 13:

PMAS:Pyrrole:oxidant	Templated Textile Electrical Resistance (KΩ/$\square$))
1:2:2	46.2 +/- 0.3
1:4:4	5.0 +/- 0.1

25

4.1.2 Templating of Polythiophenes onto PMAS Treated Wool
       Fabric

The PMAS/poly(3-methylthiophene) template was formed
30 by *in situ* polymerisation of 3-methylthiophene to PMAS

treated chlorine-Hercosett wool (171 +/- 4.3 MΩ/$\Box$)
prepared by the procedure of 1.1.1. The 3-methylthiophene
was added to the PMAS treated wool stirred in chloroform
under nitrogen. To this mixture was added a solution of
5 iron (III) chloride dispersed in chloroform and the
resulting mixture was stirred at 40°C for 2 h. After the
completion of the application, the textile sample was
removed from the application liquor and rinsed in cold tap
water until no sign of "bleed" was evident. Excess water
10 was removed and the sample was air-dried at room
temperature. The product was found to have an electrical
resistivity value of 67 +/- 2.7 KΩ/$\Box$). The reaction can
be carried out using acetonitrile as solvent but an
increased level of electrical resistivity was observed
15 (7.7 +/- 0.3 MΩ/$\Box$).

4.1.3 *In Situ* Polymerisation of Aniline on Dextran Sulfate
     Pre-treated Wool Textiles

20   A sample of the dextran sulfate (20% omf) treated
textile (Table 5) was wound onto a spindle and wet out by
soaking at room temperature with Lissapol TN450 (1
g/L,ICI, non-ionic surfactant) followed by a distilled
water rinse. Aniline (0.01 M) was added to distilled water
25 and after stirring for 1 h, the pH was adjusted to pH 1.4
with hydrochloric acid.

    The spindle was placed in the aniline solution and
stirred for 15 min using an overhead stirrer (300 rpm)at
30 2-3°C. The *in situ* polymerisation was brought about by the
drop-wise addition of a solution of ammonium
persulfate(0.0018M) in distilled water (1 drop/sec) and

the reaction left to stir overnight at 2-3°C. After the
17 h, the sample was removed, rinsed in cold water and
allowed to air dry at room temperature. The electrical
resistivity for the templated textile after the *in situ*

5   polymerisation process was 134-267 MΩ/□.

4.1.4 *In situ* Polymerisation of Aniline on other Non-
        Conductive Macromolecular Treated Wool Textiles.

10 Several other non-conductive macromolecular template
    materials were also templated with aniline by the same
    method and conditions as described above for dextran
    sulfate. The results of these experiments are shown in
    Table 14.

15

Table 14:

Macromolecular Template	Templated Textile Electrical Resistivity (MΩ/□))
α-Cyclodextrin hydrate sulfated sodium salt	12.5
β-Cyclodextrin hydrate sulfated sodium salt	13.8
4-Sulfonic Calix[6] arene hydrate	4.9

4.2   Templating using the Macromolecular Template as the
      Oxidising Agent

20

4.2.1 Oxidation of Aniline due to the Presence of PMAS
       Treated Wool.

The polymerisation of aniline was carried out in the

25 presence of a PMAS treated textile prepared by the method
    in 1.1.1. Irradiations of the treated textile in a
    solution of aniline at wavelengths of either 300 or 419 nm
    were conducted. The washed and dried samples were found

to have a decrease in electrical resistivity of 50%
compared to the original PMAS treated textile.

4.2.2 Oxidation of Pyrrole due to the Presence of PMAS
5   Treated Wool.

To an aqueous solution of pyrrole (140mg in 200ml),
adjusted to pH 1.4 with a 10% solution of HCl, was added a
PMAS treated wool fabric (1.5g, 53 MΩ/□) and the mixture
10 was allowed to stir at room temperature for 48 h in
natural light. The sample was removed, rinsed in cold
water and allowed to air dry at room temperature. The
electrical resistivity for the partially templated textile
was 29 MΩ/□.
15

5   PHYSICAL CHARACTERISATION OF MOLECULAR TEMPLATED
       TEXTILES

5.1   UV-VIS Spectral Evidence of Formation of Molecular
20   Template

The UV-VIS spectra using 1,2-dichlorobenzene of wool
textiles relating to the various stages of the *in situ*
templating process are shown in Figure 2. The increased
25 adsorption of higher wavelengths of the templated systems
is indicative of the formation of the PMAS/PAn molecular
template. The figure also demonstrates that the
characteristic PMAS band at 474 nm has decreased and
absorption around 800 nm typical of polyaniline in the
30 expanded coil form has increased.

5.2   Scotch Tape Test

Each of the electroconductive textile products produced in the Examples outlined above was subjected to the standard scotch tape test to assess bonding of the conductive polymer to the non-conductive textile. Briefly, the test involves adhering commercially available scotch sticking tape to the treated textile, peeling the tape from the treated textile and visually determining whether any polymer has been removed with the tape. All systems evaluated passed the test with no sign of removal of the ICP (see Table 15).

Table 15:

Fabric	Scotch tape test
PMAS Wool/nylon/Lycra®	No removal of polymer
PMAS/PPy Wool/nylon/Lycra®	No removal of polymer
PMAS/PAn Wool/nylon/Lycra®	No removal of polymer
PPy Wool/nylon/Lycra®	No removal of polymer
Preformed PMAS/PAn Wool/nylon/Lycra®	No removal of polymer

5.3   Effect of Washing on Conducting Polymer Treated
       Textiles

The PMAS/PAn electroconductive textile prepared by Method I (as represented in Figure 1) was subjected to a standard wash procedure. The test used was a Modified Woolmark Test Method 31, Washing of wool textile products: Standard 7A wash cycle, and was performed in a Wascator FOM 71 MP washing machine. The sample size was 100x100 mm. The results of the washing treatment were compared to a polyaniline and polypyrrole treated textile of the prior art which did not contain the macromolecular template. The results are set out in Table 16.

Table 16 also details the results of an acid treatment conducted on the same textiles. After treatment of the washed samples with aqueous sulfuric acid (pH 1.4), the PMAS/PAn treated textile shows a significant decrease in electrical resistivity whereas the polypyrrole system has increase in electrical resistivity. The polyaniline sample shows no evidence of a decrease in its electrical resistance after the acid treatment.

Table 16:

	Polyaniline (PAn)	PMAS	PMAS/PAn	Polypyrrole (PPY)
Starting textile	5.6 MΩ/□	206 MΩ/□	347 KΩ/□	11.2 KΩ/□
Washed textile*	>3.2 GΩ/□	382 MΩ/□	1.35 MΩ/□	27.5 KΩ/□
Acid wash	>3.2 GΩ/□	414 MΩ/□	811 KΩ/□	331 KΩ/□

* Modified Woolmark Test Method 31, Washing of wool textile products: Standard 7A wash cycle. Sample size was 100x100 mm

5.4   Effect of Rubbing on Conducting Polymer Treated Textiles

The colourfastness to dry rubbing of PMAS/PAn electroconductive textile prepared by Method I (as represented in Figure 1) was determined in accordance with Australian Standard 2001.4.3 – Determination of Colourfastness to Rubbing, using an Atlas Crockmeter. This test involves the dry rubbing of treated textiles using a standard undyed cotton textile (1M ISO Cotton Rubbing Fabric, supplied by Australian Wool Testing Authority). In addition to the standard 10 rubs required for the test method, extra rubs were performed. This test

showed that the PMAS/PAn molecular templated textile had less removal of conducting polymer from the textile due to abrasion than the polyaniline and polypyrrole treated textiles. The alternative molecular templated textile,

5 PMAS/PPY had improved rubfastness compared to the textile treated with only polypyrrole.

Table 17:

	Polyaniline (PAn)	PMAS	PMAS/PAn	PMAS/PPY	Polypyrrole (PPY)
Perpendicular					
10 rubs	4	4	4	4	3-4
20 rubs	3-4	3-4	3-4	3-4	3
30 rubs	3	3-4	3-4	3-4	2-3
40 rubs	3	3-4	3	3-4	2-3
Parallel					
10 rubs	3-4	4-5	4	4	3-4
20 rubs	3	4	3-4	4	3
30 rubs	3	3-4	3-4	3	3
40 rubs	3	3-4	3-4	3-4	3

10 Grey scale ratings 5 to 1 white through to grey. A rating of 5 indicates that no polymer is abraded onto the white cotton test fabric.

6   *IN SITU* TEMPLATED COATINGS AS WEARABLE TEXTILE
15   STRAIN GAUGES.

The effect on electrical resistance due to the straining of a range of PMAS/PAn molecular templated wool/composite textiles was determined. The dynamic

20 calibrations at frequencies up to 3 Hz and over a range of 10-70% strain showed that the results compared well with those obtained using *in situ* coated polypyrrole on

Nylon/Lycra®. Unlike the polypyrrole-coated materials, minimal change in electrical resistance responses was observed over a three-week period for the PMAS/PAn electroconductive textiles.

5

It will be understood to persons skilled in the art of the invention that many modifications may be made without departing from the spirit and scope of the invention.

10